Extreme Environment Materials

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Outline

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- Trends in Power Generation and Market Drivers
- Ultra-High Materials Development by Materials Community
- Industrial Approach for Gas Turbine Materials/Coatings
- Additive Manufacturing (AM) Technology Landscape
- System Level Engineering of Extreme Environment Materials
- Materials Related Turbine Development Goals for Gas Turbines
- Progressive Development Approach

An integrated approach to advanced materials and coatings development with rigorous validation is the future for extreme environment materials

Siemens Provide a Range of Gas Turbine Products for Both 50 Hz and 60 Hz Grids

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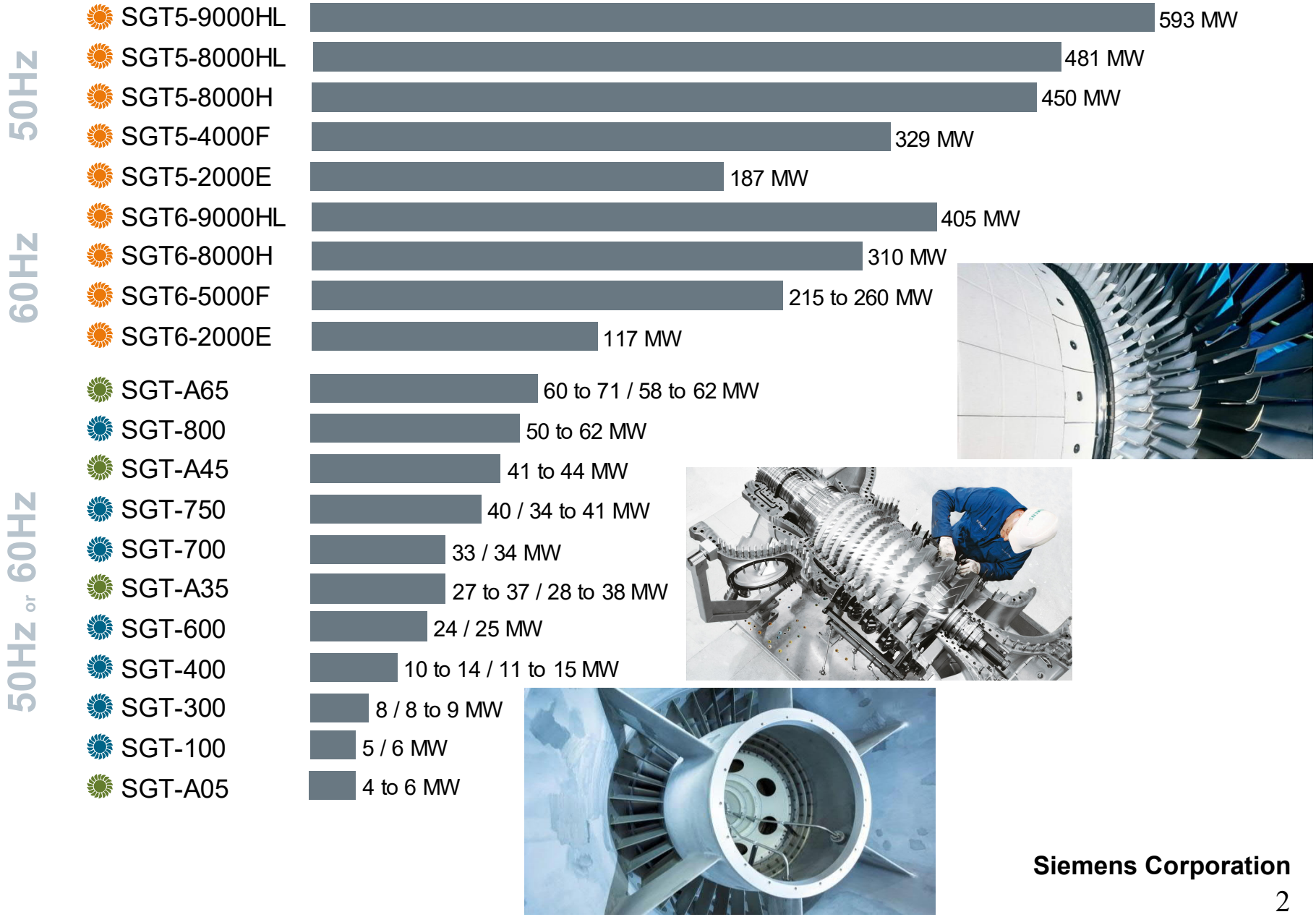
Heavy-duty gas turbines

Industrial gas turbines

Aeroderivative gas turbines



Customer Needs and Market Drivers for Materials & Coatings for Industrial Gas Turbines

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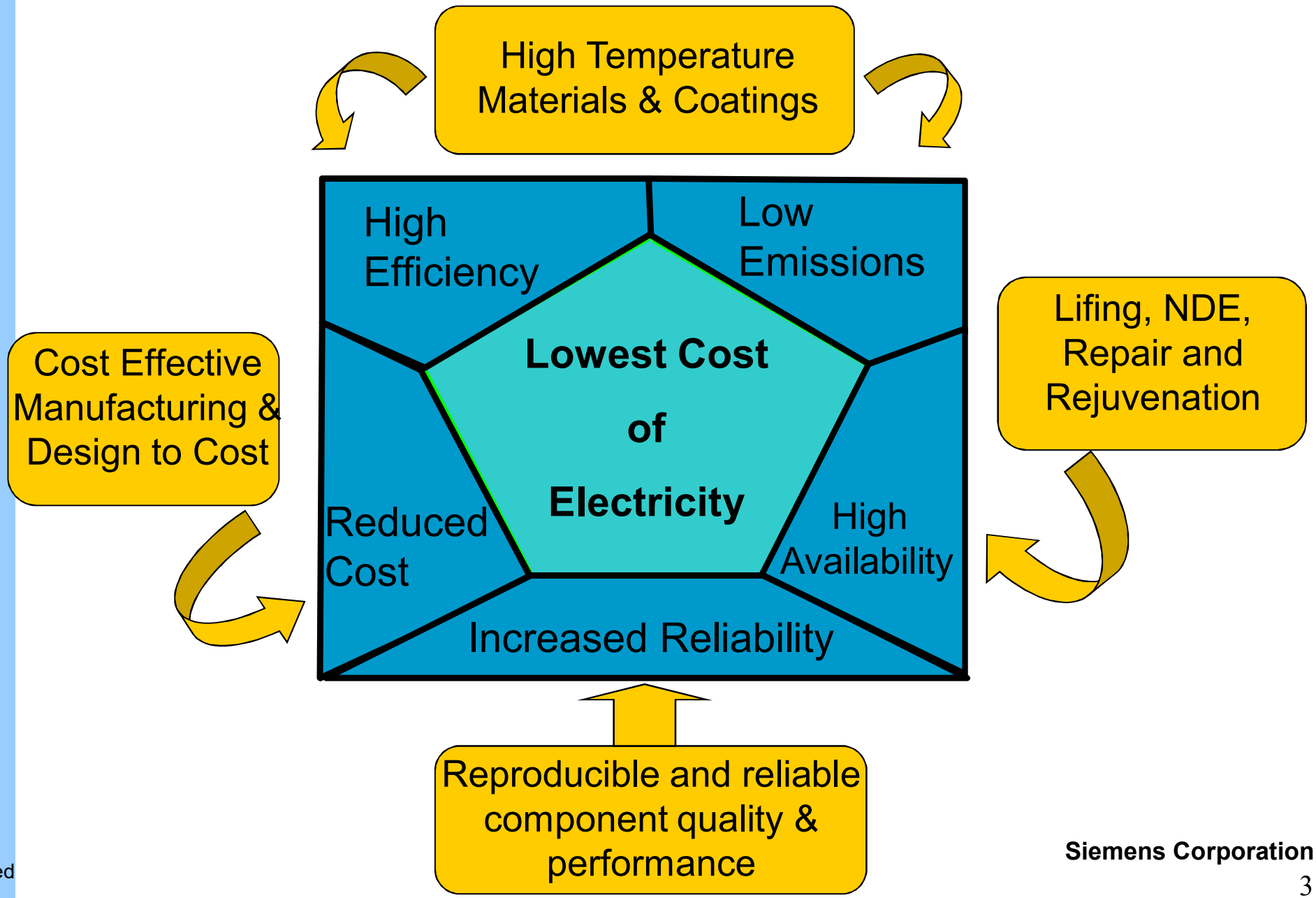

Ultra-High Materials Development by Materials Community

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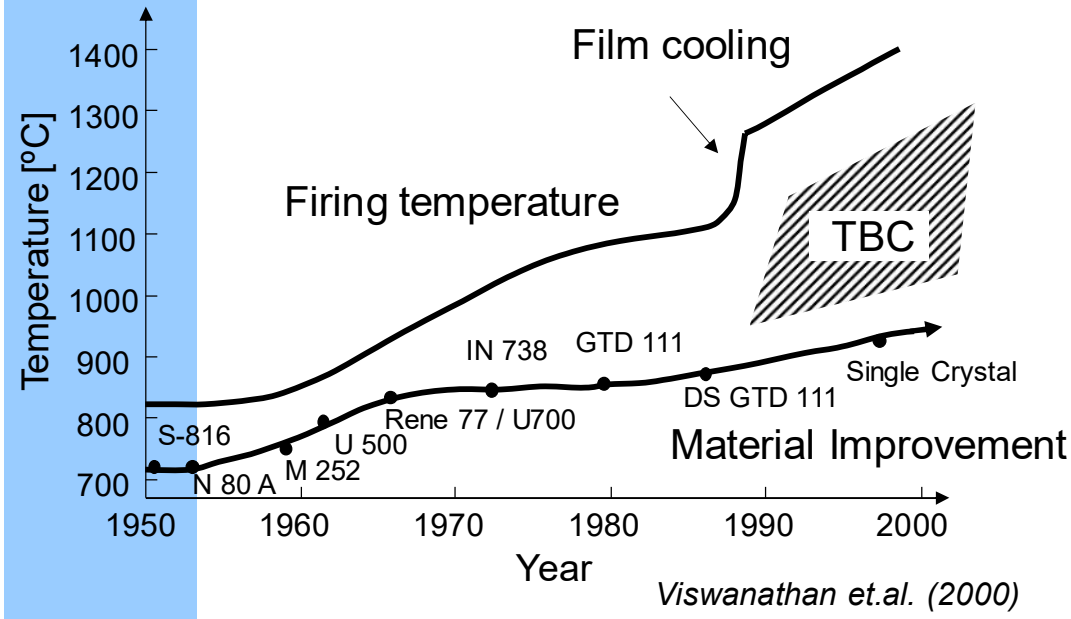
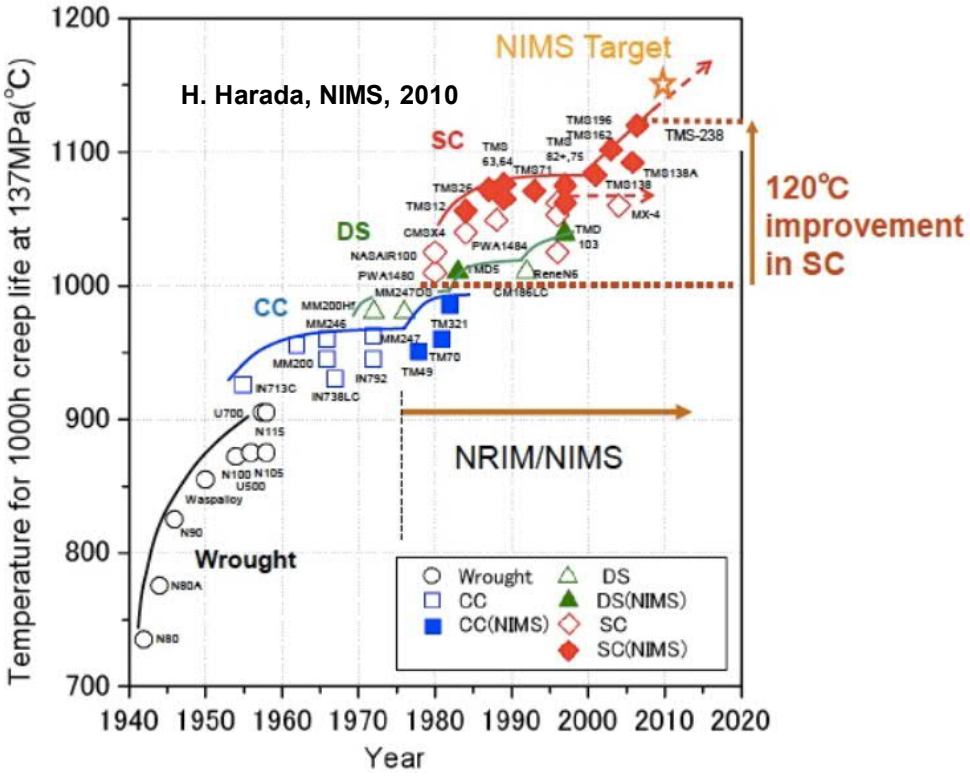
Currently, high temperature materials are limited to approx. 1100 ºC.

In order to achieve the goal of gas turbine power plants with η = 65% (Flame temperature: 1800ºC), materials with near gas temperature capabilities have to be developed.



Viswanathan et.al. (2000)



200ºC improvement in 50 years, 250ºC improvement desired in 20 years

Industrial Approach for Gas Turbine Materials/Coatings

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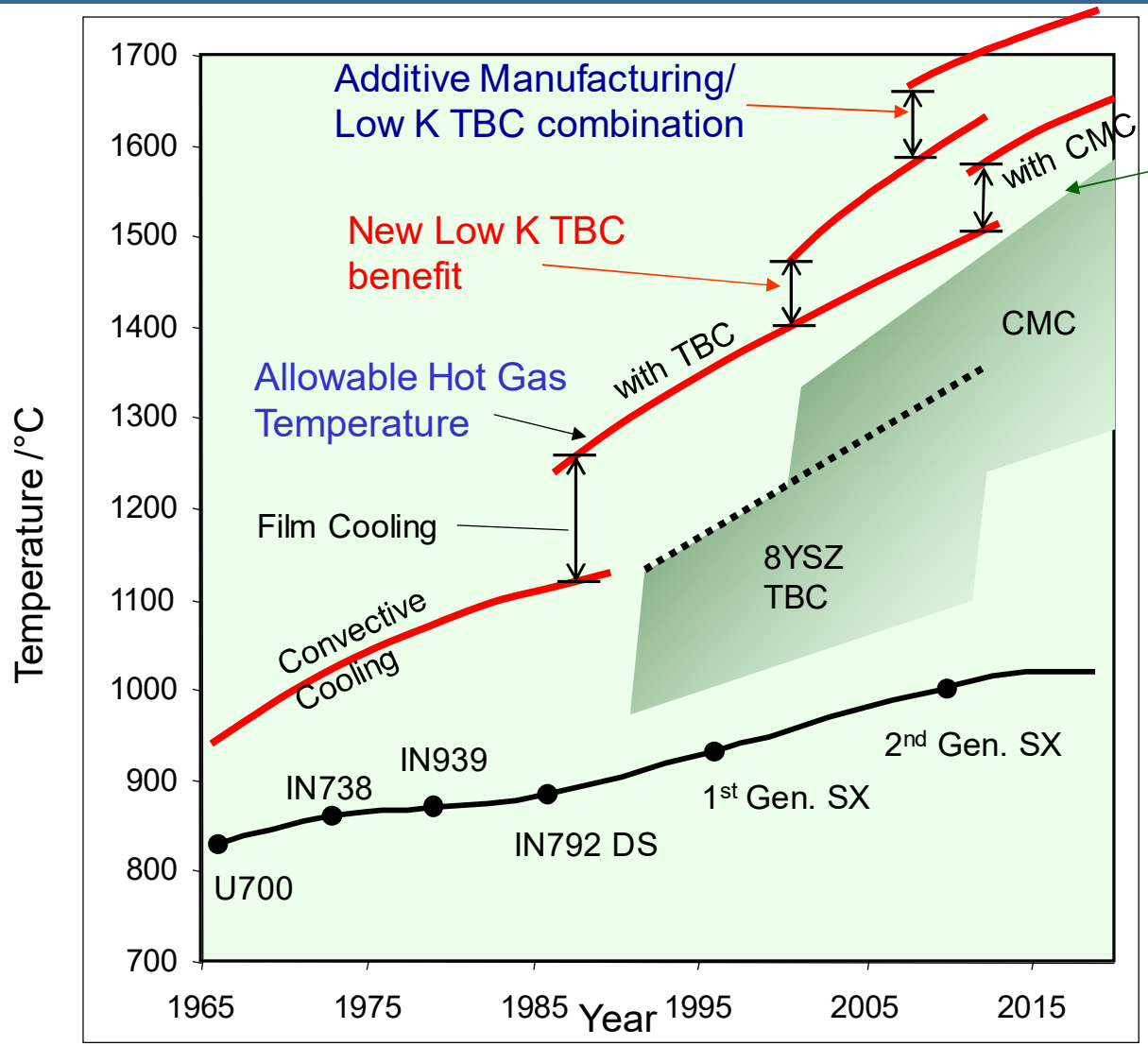

TBC – Thermal barrier coatings

Need Design input on engine conditions and environments for technology download

Additive Manufacturing (AM) Technology Landscape

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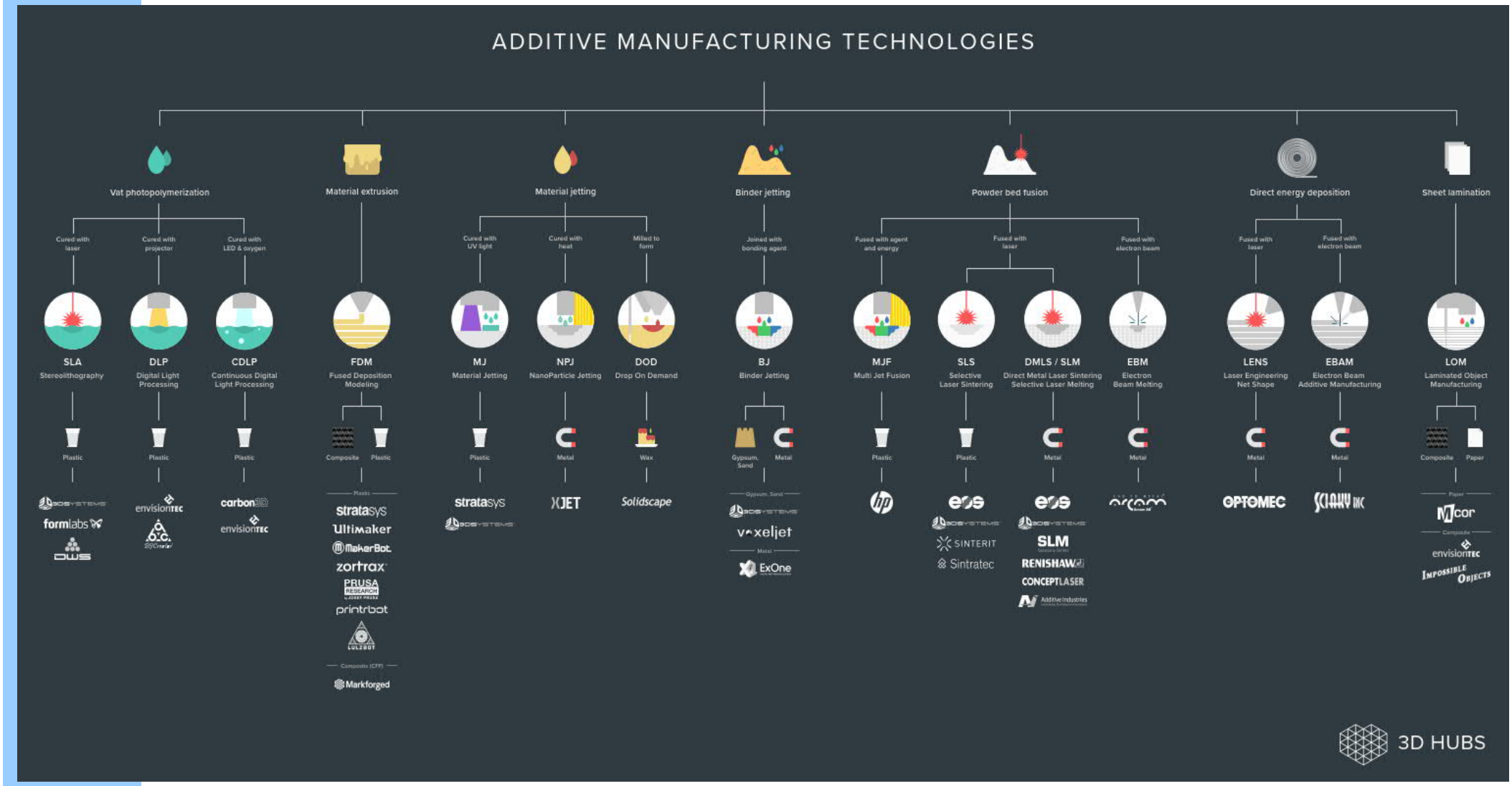

Growing number of AM processes to accelerate the development of materials and their qualification

Testing and Validation Chain
Change in R&D paradigms

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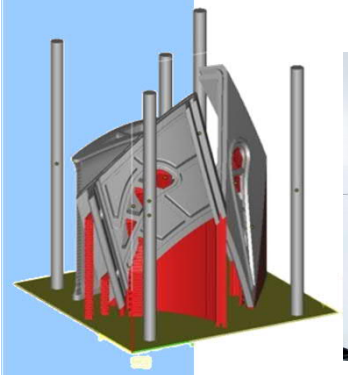
Integrated development: accelerated iteration cycles in few months

3D Design → **AM processing** → **Post processing** → **Instrumentation** → **Testing**



Clean Energy Center

Conventional process

"Testing is final validation at the end of development process"

- Sequential development processes
- Conservative development approach
- Moderate development goals
- Long development cycles

Novel paradigm

"Testing is integrated part of development process"

- Parallel and integrated development processes
- Radical development approaches
- Ambitious development goals
- Accelerated development goals, short iteration cycles

Additive Manufacturing: Potential benefits of AM for GT

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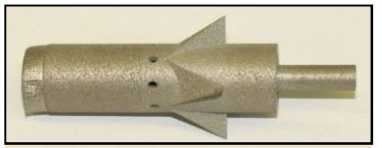
Product costs	**Cost reduction** for manufacturing of complex parts in smaller volume, **reduced LCC** (service, repair)
Validation	**Faster validation** of new technologies and designs with minimized effort and lead time by use of **rapid prototyping for rig test** and later functional parts
Time-to-market & development costs	**Reduced lead time and costs** for prototype development by use of **rapid prototyping, rapid tooling** and rapid qualification techniques
Efficiency & Performance	**Increased** product design **complexity** far beyond today's level enabled by **new manufacturing technologies** at competitive costs



Design Flexibility/Topology Optimization for Redesign of Components

System Level Engineering of Extreme Environment Materials

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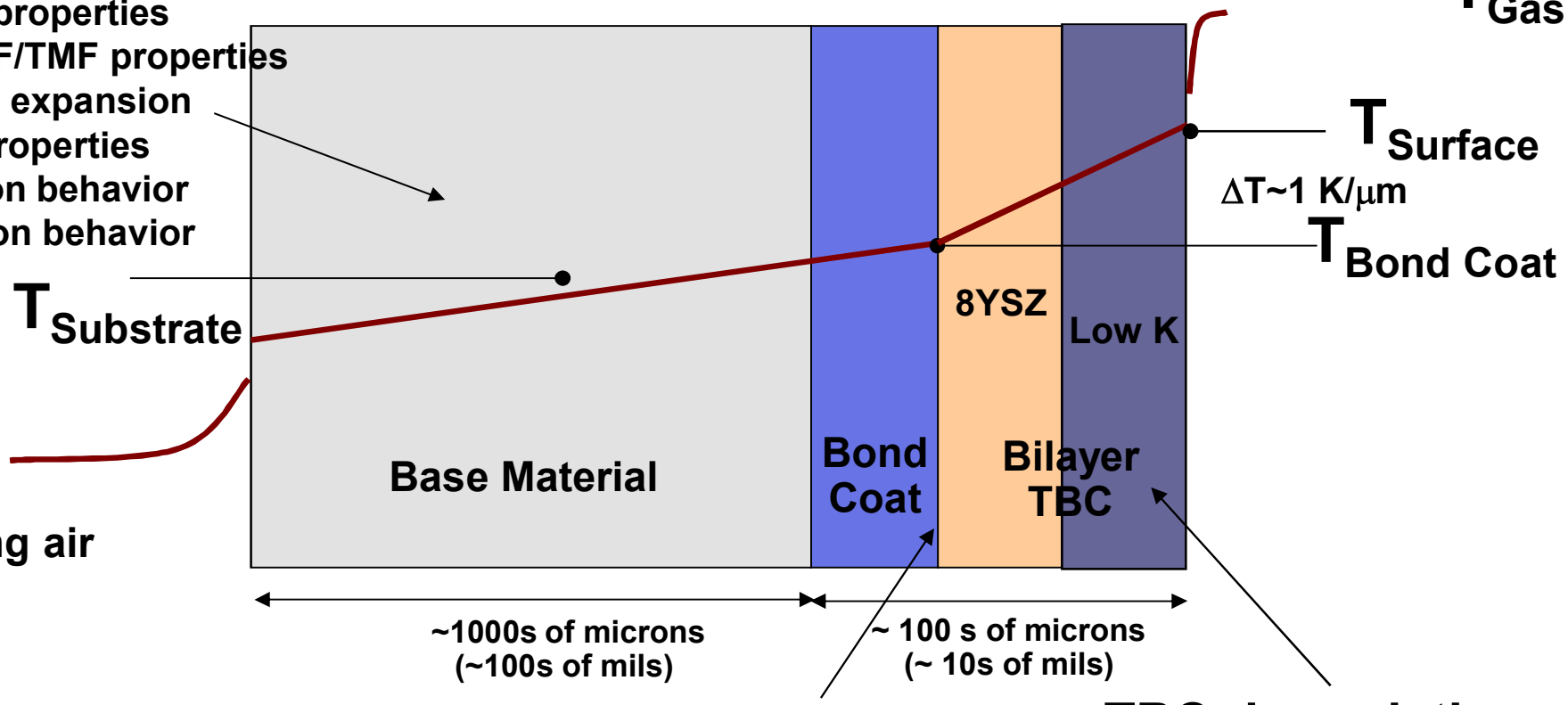
Base alloys mechanical/ oxidation properties

- Tensile properties
- LCF/HCF/TMF properties
- Thermal expansion
- Creep properties
- Oxidation behavior
- Corrosion behavior



Bond coat oxidation

- reduced fracture resistance at TBC/ BC interface (TGO growth stress)
- degradation of BC properties (Al depletion) with HEA alloy

TBC degradation

- reduced TBC fracture resistance (strain tolerance)
- increased TBC stiffness and thermal conductivity/Sintering
- possible phase transformation

Observed Coating Failure Mechanisms

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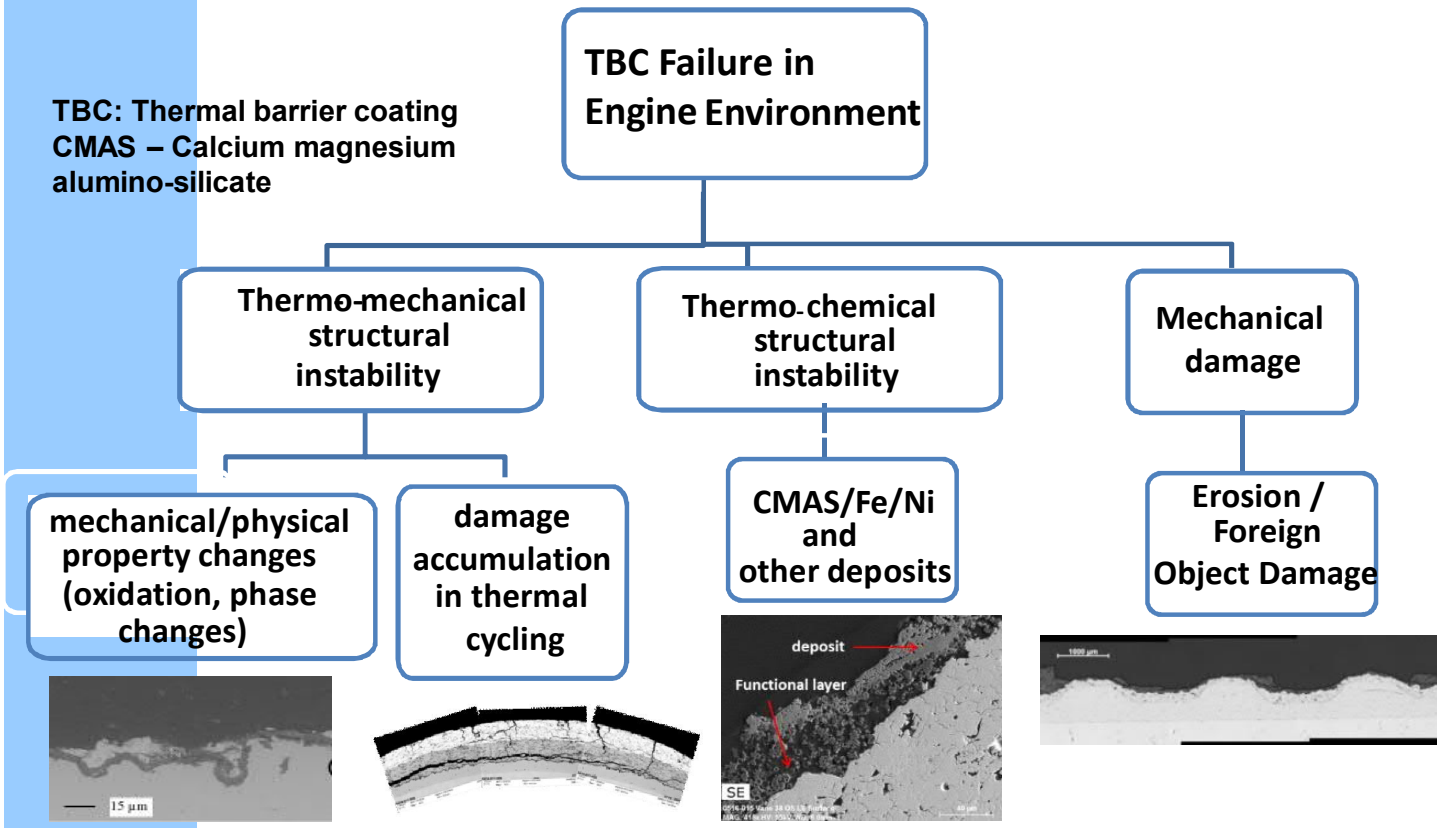
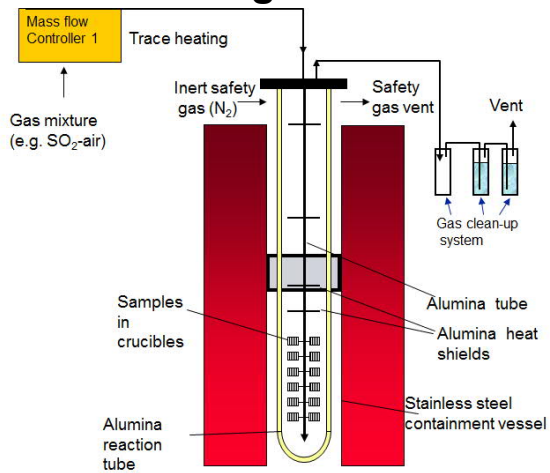
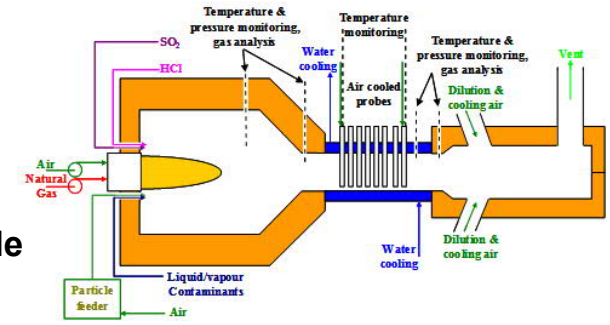
TBC: Thermal barrier coating
CMAS – Calcium magnesium alumino-silicate



Isothermal/ Pressured Rig tests



Burner rig tests



Combination of tests needed to address risk/quantitative degradation for fuel flexible environments

- Testing provides Insight into degradation mechanism
- Component specific conditions (Ttbc/Tmetal) in gradient testing
- Reactions between TBC/bond coat with corrosives/metal loss

Critical Components have coating protection, System reliability needed in fuel flexible environments

Risk from Contaminants (Ca, Na, Ni, Fe, S, V)

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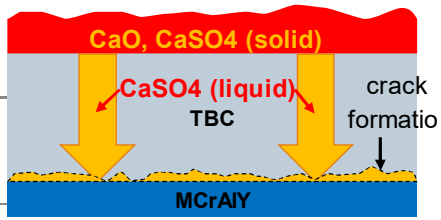
- Environmental Factors
  - Salt composition and its melting temperature
  - Testing temperature and thermal cycles
  - Gas composition
  - Salt deposition rate
  - Thickness of salt layer
  - Prior environmental exposure (*e.g.* oxidizing environment)
- Compositional Factors
  - Alloy composition
  - Composition and thickness of thermally grown oxides (TGO)

Calcium Sulfate hot corrosion on turbine blade



Vanadium hot corrosion on turbine blade

Sodium Sulfate hot corrosion on turbine blade

Materials Related Turbine Development Goals for Industrial Gas Turbines

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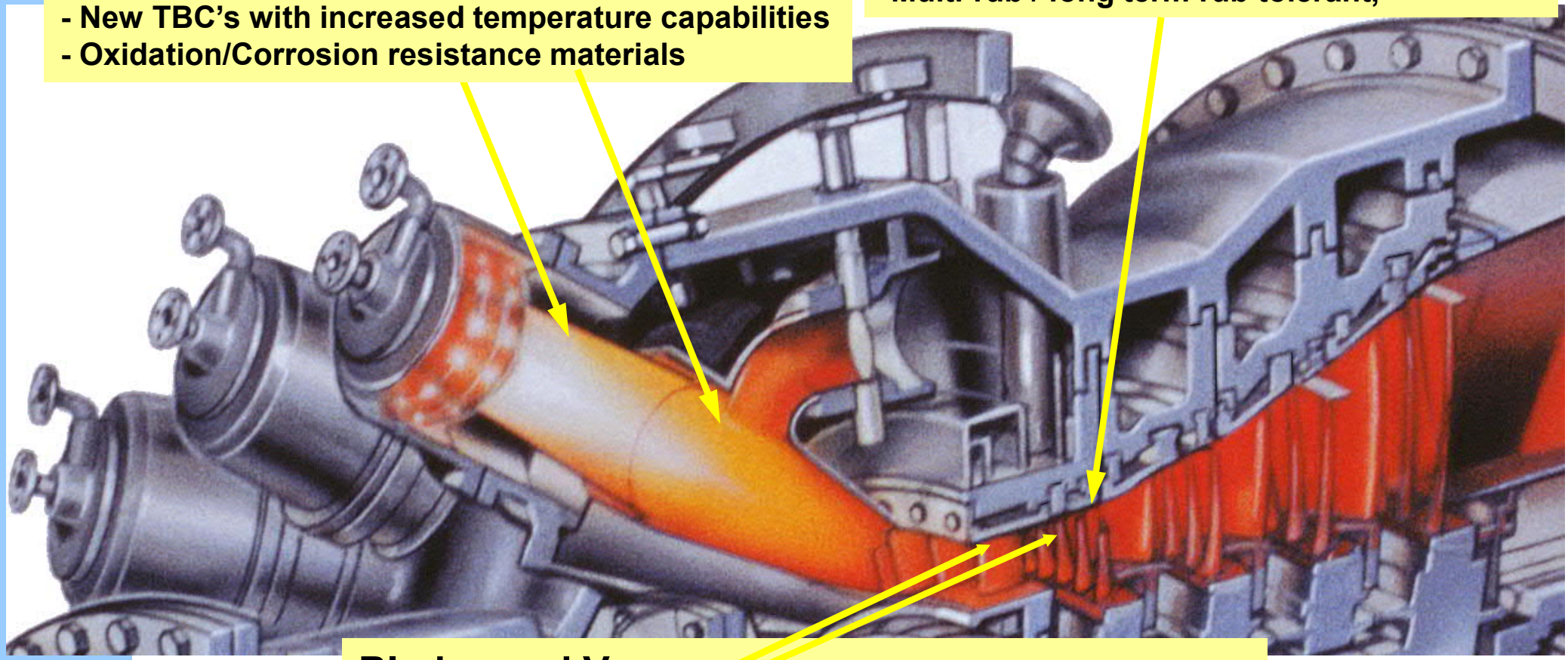
Combustors and Transitions

- Metallic coatings, increased oxidation resistance
- New TBC's with increased temperature capabilities
- Oxidation/Corrosion resistance materials

Ring Segments

-Increased temperature abradable coatings
-Multi-rub / long term rub tolerant,



Blades and Vanes

- New TBC's with increased temperature capabilities
- Materials with oxidation/corrosion/fatigue/creep resistance
- New metallic coatings, increased oxidation resistance
- Materials life prognosis and health monitoring

Progressive Development Approach

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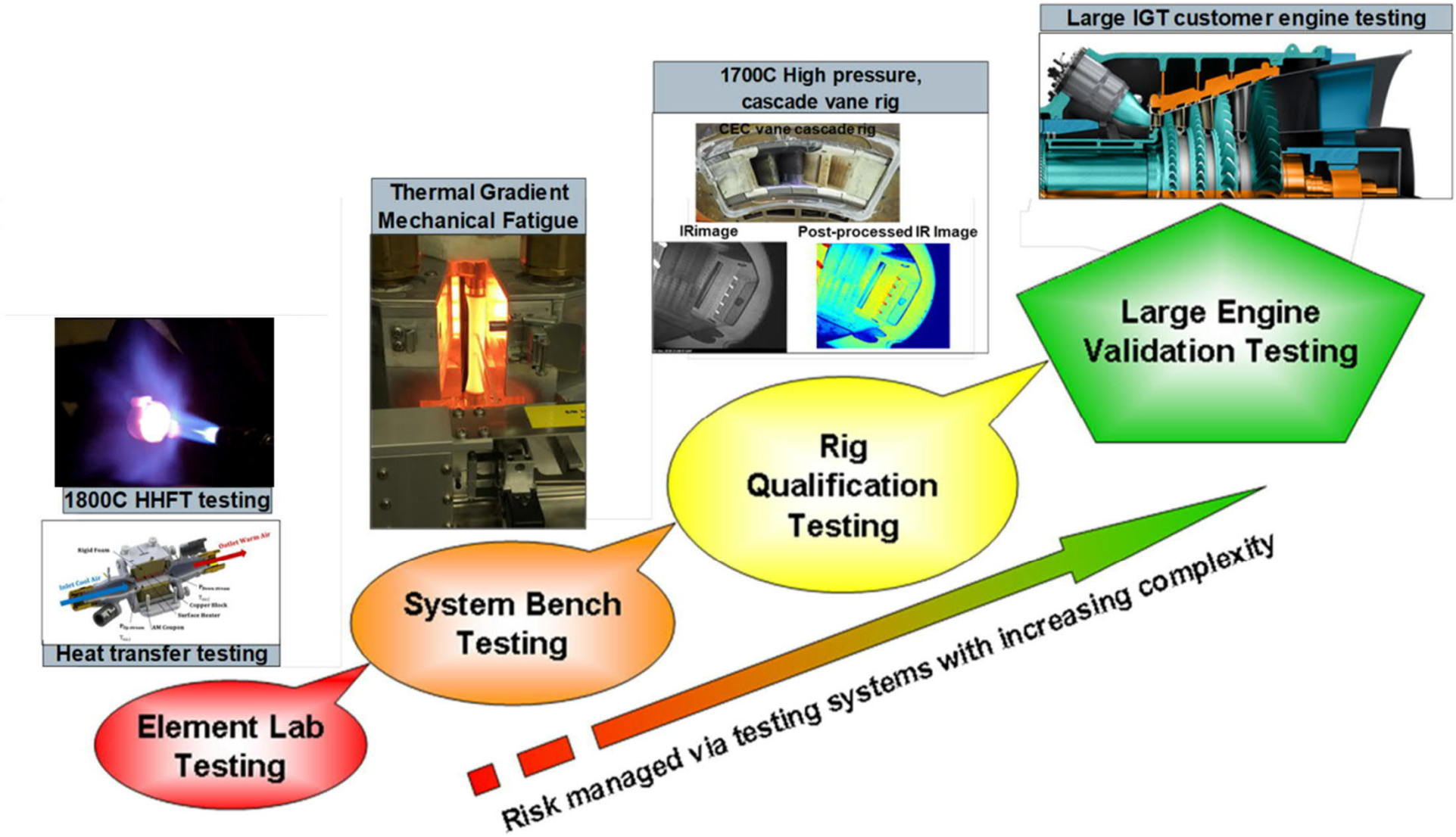

Rigorous testing and validation based on a thorough understanding of failure modes and improving final system performance